

Code of practice for

Control of undesirable static electricity —

Part 1: General considerations

Committees responsible for this British Standard

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- British Plastics Federation
- British Textile Technology Group
- Chief and Assistant Chief Fire Officers' Association
- ERA Technology Ltd.
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- General Council of British Shipping
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- Institution of Electrical & Electronics Incorporated Engineers
- Institution of Electrical Engineers
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Foreword

This Part of BS 5958 was prepared under the direction of the General Electrotechnical Standards Policy Committee. It replaces BS 5958-1:1980 which is withdrawn.

This edition introduces technical changes to bring the standard up-to-date but it does not reflect a full review of the standard, which will be undertaken in due course.

Static electricity occurs commonly in industry and in daily life, and can be a source of danger as well as discomfort or inconvenience. The main hazard is that of explosions and fires initiated by electrostatic discharges, but shocks to personnel can also, on occasion, cause accidents. In addition, static electricity introduces operational problems during manufacturing and handling processes, e.g. by causing articles to adhere to each other or to attract dust. It is generated in many operations, including the flow of liquids or powders, the production of sprays and the contact and separation of solids. It therefore gives rise to problems in a wide range of industries, e.g. chemicals, pharmaceuticals, petroleum and textiles.

The purpose of this Part of BS 5958 is to provide recommendations for the control of static electricity. In some cases static electricity is an integral part of a process, e.g. paint spraying, but more often it is an unwelcome side effect and it is with the latter that this Part of BS 5958 is concerned. Often, static electricity will not be the only source of ignition present, and antistatic precautions should be formulated so as to be consistent with the measures required to deal with other ignition risks.

This Part of BS 5958 does not provide recommendations for the control of static electricity in the transport, handling, storage or testing of electrostatic sensitive electronic devices (ESDs) or circuits. Reference should be made to BS 5783¹⁾ for this purpose.

Although lightning is a form of static electricity, it is not intended that this Part of BS 5958 be used to obtain guidance on the protection of structures against lightning. For this purpose, reference should be made to BS 6651.

BS 5958 is in two Parts. BS 5958-2 provides simple recommendations for controlling static electricity in a variety of specific operations, the justification for which should be sought in this Part of BS 5958. Static phenomena are encountered so widely that it is not possible to cover all cases and, if adequate guidance is not found in BS 5958-2, this Part should be consulted. If there is still doubt, expert advice should be sought; research on the subject continues and new information is still coming to light.

¹⁾ BS CECC 00015-1 is in preparation and will supersede BS 5783:1987.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 46, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This Part of BS 5958 gives basic information on the generation of undesirable static electricity in solids, liquids and gases, and also on persons, and describes how the charges produced give rise to discharges which may cause ignitions or electric shocks. It gives the methods available for minimizing such generation and for safely dissipating the charges produced. Section 4 deals with the principles of earthing and bonding as applied to avoid static electricity hazards. Appendix A gives guidance on the means of measuring or estimating the parameters which need to be taken into account when deciding upon the action to be taken to control static electricity.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard, the following definitions apply.

2.1

antistatic; conductive

used as an adjective to indicate that a material is, by virtue of its low resistivity, incapable of retaining a significant electrostatic charge when in contact with earth

NOTE The terms “antistatic” and “conductive” are frequently used as synonyms, hence the common definition. However, in contexts where they have specific meanings, e.g. in relation to footwear, this definition is qualified in the appropriate clauses of this Part of BS 5958.

2.2

antistatic additive

a substance added to a liquid or a solid in order to increase its conductivity so that it is incapable of retaining a significant electrostatic charge when in contact with earth

2.3

bonding

the use of an additional independent connection between conductors to provide electrical continuity when this cannot otherwise be ensured

2.4

breakdown strength

the minimum electric field strength in a medium at which electrostatic discharges can occur in a given situation

2.5

conductivity

the reciprocal of resistivity

2.6

conductor

a material possessing an electrical conductivity sufficiently high to render it incapable of retaining an electrostatic charge unless insulated from earth

2.7

earthing

the electrical connection of a conductor to the main body of the earth to ensure that it is at earth potential

2.8

flammable

capable of being ignited

2.9

flammable material

a gas, vapour, liquid, dust or solid that can react continuously with atmospheric oxygen and that may therefore sustain fire or explosion when such reaction is initiated by a suitable spark, flame or hot surface

NOTE 1 Many liquids and solids, though regarded as flammable, nevertheless do not normally burn. The application of heat to such materials serves to release vapour that may burn with atmospheric oxygen. The heat of the subsequent reaction serves to release further vapour for combustion. Flame may propagate through suspensions of dusts by this mechanism.

NOTE 2 In normal usage “gas” and “vapour” are synonymous.

2.10

flammable mixture; explosive mixture

a mixture with air of a flammable material, in the form of a gas, droplets or dust, which is within the flammable range and therefore capable of being ignited

2.11

flammable range

the range of concentrations in air of a flammable material, in the form of a gas, droplets or dust, between the lower and upper flammable limits

2.12

hazardous area

an area in which flammable or explosive gas-air mixtures are, or may be expected to be, present in quantities such as to require special precautions against ignition

hazardous areas are classified into the following three zones (see BS 5345-1)

- a) *Zone 0*: zone in which an explosive atmosphere is continuously present, or present for long periods.
- b) *Zone 1*: zone in which an explosive atmosphere is likely to occur in normal operation.
- c) *Zone 2*: zone in which an explosive atmosphere is not likely to occur in normal operation, and if it occurs it will exist only for a short time.

2.13**incendive**

capable of igniting a prescribed flammable mixture

2.14**inert gas**

a gas or a mixture of gases incapable of supporting the combustion of a flammable material

2.15**ion**

an atomic or molecular particle carrying electrical charge

2.16**lower flammable limit**

the concentration in air of a flammable material, in the form of a gas, droplets or dust, below which there is insufficient of the material to support and propagate combustion

2.17**mass charge density**

the nett quantity of charge carried by unit mass of a material

2.18**minimum ignition energy**

the smallest quantity of energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure

2.19**non-conductor**

a material possessing an electrical resistivity sufficiently high to enable it to retain enough charge to give rise to electrostatic effects

2.20**relaxation**

the dissipation of an electrostatic charge by conduction

2.21**relaxation chamber**

a part of a liquid flow system which provides sufficient residence time for the charge on the liquid to be reduced to a safe level

2.22**relaxation time**

the time required for the charge or potential on a liquid or a solid to decay to $1/e$ of its original level (e is the base of natural logarithms)

2.23**surface charge density**

the nett quantity of charge per unit area of the surface of a solid or a liquid

2.24**surface resistivity (of a substance)**

the resistance between the opposite edges of a square

2.25**upper flammable limit**

the concentration in air of a flammable material, in the form of a gas, droplets or dust, above which there is insufficient of the air to support and propagate combustion

2.26**volume resistivity (of a substance)**

the resistance at unit length and unit cross-sectional area

Section 2. Fundamentals of static electricity

3 Electrostatic charging

3.1 General

The primary source of electrostatic charge is contact electrification, where two dissimilar materials are brought into contact and then separated, carrying equal and opposite charges. Conducting objects may also become charged by the process of induction from another charged object or objects in the vicinity. Objects can also receive charge by direct transfer either from other objects or by the impingement upon them of a stream of ions.

3.2 Contact electrification

Contact electrification can occur at solid/solid, liquid/liquid or solid/liquid interfaces. Gases cannot be charged in this way, but if a gas has solid particles or liquid droplets in suspension these may be charged by contact, so that such a gas can carry an electrostatic charge.

In the case of dissimilar solids, initially uncharged and at the same, normally earth, potential, a small amount of charge is transferred from one material to the other when they make contact. The two materials are therefore oppositely charged and there is a potential difference between them which is of the order of 1 V. If the materials are then separated, work has to be done to overcome the attraction between the opposing charges and the potential difference between them therefore increases. This higher potential difference tends to drive charge back across the interface whilst any contact remains. In the case of two conductors the recombination of charges is virtually complete and no significant amount of charge remains on either material after separation. If one material, or both, is a non-conductor, the recombination cannot take place completely and the separating materials hold part, at least, of their charges. Because the clearance between the surfaces when in contact is extremely small, the potential generated on separation can easily reach many kilovolts despite the small amount of charge involved. For reasons not fully understood the charging is enhanced if the contact and separation involves rubbing.

Contact electrification in liquids depends on the presence of ions or sub-microscopic charged particles (the latter are usually less important). Ions (or particles) of one polarity are adsorbed at the interface and they then attract ions of opposite polarity which form a diffuse layer of charge close to the surface. If the liquid is then moved relative to the interface, it carries away this diffuse layer, thereby bringing about separation of the opposing charges. As in the case of solids a high voltage is generated because of the work done to bring about the separation, provided that the liquid is sufficiently non-conducting to prevent recombination. Such processes can occur at both solid/liquid and liquid/liquid interfaces.

3.3 Charging by induction

There is an electric field around any charged object. A conductor introduced into this field changes the distribution of potential in the field in its vicinity and at the same time there is a separation of opposing charges in the conductor under the influence of the field. If it is insulated the conductor takes up a potential, dependent upon its position in the field, and is said to be charged by induction. By virtue of its potential, coupled with the separated charges that it carries, the conductor is capable of an electrostatic discharge.

If, while it is in the field, the conductor is momentarily earthed, its potential is reduced to zero, but an imbalance of charges remains on it. Removal of the conductor from the vicinity of the original charged object, however, makes the remaining charge available to provide a spark. This type of induction sparking can be hazardous, for example in the case of an insulated person moving about near electrostatically charged materials.

3.4 Charge transfer

Whenever a charged object makes contact with one that is uncharged, the charge is shared between them to the extent that their conductivities allow. This is a potent source of electrostatic charging when charged sprays, mists or dusts impinge upon a solid object, for example by settling. A similar transfer of charge can also take place when a stream of gaseous ions is incident upon an initially uncharged object.

4 The retention of electrostatic charge

Even after separation in the charging process, electrostatic charges will quickly recombine either directly or via the earth unless they are prevented from doing so. If a charge is on a non-conductor it is retained by virtue of the resistance of the material itself. To retain charge on a conductor it has to be insulated from other conductors and from earth by means of a non-conductor. It is shown in 13.2 that to retain a significant electrostatic charge a resistance to earth in excess of $10^6 \Omega$ is required.

Pure gases under normal conditions are non-conductors and the suspended particles, or droplets, in dust clouds, mists or sprays can therefore retain their charges, often for very long periods, irrespective of the conductivity of the particles themselves.

In all cases the charge leaks away at a rate determined by the resistances of the non-conductors in the system. This process is known as relaxation. The resistance and resistivity or conductivity values which are needed to produce hazardous situations depend greatly upon the system under consideration and will be discussed in section 3.

In many industrial processes there is a continuous generation of static electricity which accumulates on an insulated conductor, e.g. when a steady stream of charged liquid or powder flows into an insulated metal container. The potential on the insulated conductor is then the result of a balance between the rate of input of charge and the rate of leakage. The equivalent electrical circuit is shown in Figure 1 and the potential of the conductor is given by the following equation:

$$V = IR \left[1 - e^{-\frac{t}{RC}} \right]$$

where

V is the potential of the conductor (in V);

C is its capacitance (in F);

R is the leakage resistance to earth (in Ω);

I is the electrostatic charging current (in A);

t is the time from the commencement of charging (in s).

The maximum potential is reached when t is large and is, therefore,

$$V_{\max} = IR.$$

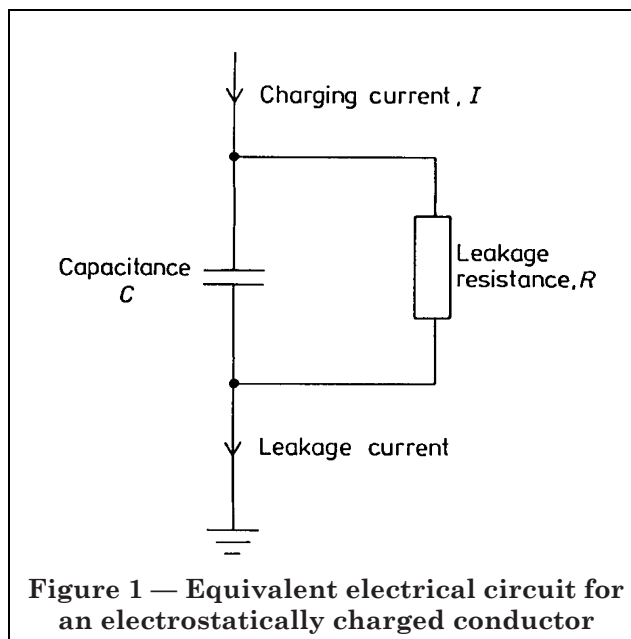


Figure 1 — Equivalent electrical circuit for an electrostatically charged conductor

5 Electrostatic discharges

5.1 General

Charge retained on a liquid or a solid creates a hazard only if it is discharged to another body or, more usually, to earth. Electrostatic discharges vary greatly in type and incendivity. In this Part of BS 5958 they are classified as described in 5.2 to 5.6, although the differentiation between the various types is not completely definite.

5.2 Sparks

A spark is a discharge between liquid or solid conductors. It is characterized by a well defined luminous discharge channel carrying a high density current. Ionization of gas in the channel is complete over its whole length. The discharge is very rapid and gives rise to a sharp crack.

A spark occurs between conductors when the field strength between them exceeds a level known as the breakdown strength, which depends upon the gap width. For flat or large radius surfaces 10 mm or more apart this field strength is about 3×10^3 kV/m and it increases somewhat as the gap decreases.

Because the bodies concerned in the discharge are conductors, all the charge is drawn into the spark, which in most practical cases dissipates almost all the available energy. Referring to the equivalent electrical circuit of Figure 1, therefore, the energy of the spark is

$$E = \frac{1}{2} QV = \frac{1}{2} CV^2$$

where

E is the energy dissipated (in J);

Q is the quantity of charge on the conductor (in C);

V is its potential (in V);

C is its capacitance (in F).

This is the maximum value of energy; the energy in the spark is less if there is resistance in the discharge path to earth, and the duration of the spark is then also greater.

Typical values for the capacitances of conductors are given in Table 1.

A typical calculation of spark discharge energy is that involved when an unearthed metal drum is filled with powder from a grinding unit. In such a case the electrostatic charging current, I , might be 10^{-7} A. The leakage resistance of the drum to earth, R , is, for example, $10^{12} \Omega$ and its capacitance about 50 pF. The maximum voltage on the drum is then

$$V_{\max} = IR = 100 \text{ kV}$$

and the maximum energy released in a spark discharge would be

$$E_{\max} = \frac{1}{2} CV_{\max}^2 = 250 \text{ mJ.}$$

The charge retained on the drum to give a potential of 100 kV is

$$Q_{\max} = CV_{\max} = 5 \times 10^{-6} \text{ C}$$

Table 1 — Typical electrical capacitances

Object	Capacitance
	pF ^a
Small metal items (scoop, hose nozzle)	10 to 20
Small containers (bucket, 50 L drum)	10 to 100
Medium containers (250 L to 500 L)	50 to 300
Major plant items (reaction vessels) immediately surrounded by earthed structure	100 to 1 000
Human body	100 to 300
^a 1 pF = 1×10^{12} F.	

5.3 Corona

This is a form of discharge from a conductor when it is very small, pointed, or has a sharp edge, i.e. where a surface with a small radius of curvature exists. The discharge may be directed towards another object, or it may be dissipated into the atmosphere.

The field strength near the pointed feature is very large and falls off rapidly with increasing distance from it. The gas adjacent to the point is ionized and current can therefore leave the conductor. However, farther away from the point ionization is not complete and a low stable current is set up which is controlled by the gas conduction in this area. It is known as a corona discharge and is characterized by a hissing sound and, sometimes, by a faint glow.

A corona discharge may continue indefinitely or it may be in discrete short bursts. The energy density in the discharge is much less than in a spark. In certain circumstances, e.g. if there is an increase in the potential of the pointed conductor, corona can develop into a spark to another object.

5.4 Brush discharges

Brush discharge occurs from a charged non-conductor to a conductor. It takes the form of short spark-like discharges from discrete areas of the surface of the non-conductor. The total discharge often has a brush-like appearance. If the conductor to which the current is flowing is pointed, the discharge at the conductor will be in the form of corona.

The localized energy density in a brush discharge may be high enough to be incandescence; empirical tests suggest, however, that the equivalent energy release is unlikely to exceed about 4 mJ.

5.5 Propagating brush discharges

This type of discharge is a development of the normal brush discharge which can occur from a high resistivity non-conductor in sheet form with large opposing charges on its two surfaces. Often the sheet is backed by a conductor, but the essential point is that the sheet is polarized and in the same state as the dielectric of a charged capacitor. If a conductor approaches the non-conductor surface the resultant electrostatic field promotes ionization across a large area of the surface. A discharge can then take place in which the charge from an extensive area of the non-conductor rapidly flows to the initial discharge point through the ionized gas adjacent to the surface. The result is an intense and highly energetic spark-like discharge which can be very dangerous.

5.6 Field emission discharges

The energy of this type of discharge is very small and it is likely to be of concern only when explosives are involved. The discharges described in 5.2 to 5.5 have all depended upon gas ionization brought about by high field strength, but it is believed that a different ionization process operates in field emission discharges, i.e. possibly the ejection of electrons from the surfaces; surface condition appears to be important. Discharges have been observed with a potential difference of 50 V if two conductor surfaces are brought within a distance of 10^{-3} mm of each other, which is equivalent to a field strength of about 5×10^4 kV/m. These figures compare with a field strength of about 3×10^3 kV/m for the more usual discharges, with a threshold potential difference of about 300 V.

6 Incendivity of electrical discharges

NOTE The data given in clause 6 is only appropriate at ambient temperatures and pressures. At other temperatures and pressures the flammability and explosibility characteristics may change and specialist advice should be sought.

6.1 Flammability and explosivity

6.1.1 Flammable mixtures

In the combustion process a flammable material reacts with an oxidant to liberate energy. The oxidant is usually air but it can be another gas mixture, containing more or less oxygen than air, or some other oxidizing agent.

A mixture in air of a flammable material in the form of a gas, droplets or dust cannot burn unless its composition lies within two limits, known as the lower and upper flammable limits and normally expressed in terms of the concentration of flammable material in air. The range of concentrations between these limits is known as the flammable range, and any mixture within this range is termed a flammable mixture. The majority of gases have flammable limits within the range 2 % V/V to 10 % V/V. However, there are substances, e.g. acetylene, ethylene and hydrogen, whose flammable limits exceed this range (see BS 5345-1).

For a mixture of gas and dispersed dust the flammability characteristics of the gas/dust mixture should be considered.

In general, it is possible to avoid an explosion hazard due to an electrostatic discharge, or any other source of ignition, by eliminating any flammable mixture that is present. This can be done either by ventilation with air to reduce the concentration of the flammable material below the lower flammable limit or by adding inert gas. An inert gas is one containing little or no oxygen, such as boiler flue gas, and by its use the oxygen content of the atmosphere can be reduced to such a low figure that combustion is not possible at any concentration of flammable material in air. The required oxygen concentrations are, for example, about 11 % V/V for hydrocarbon gases and about 5 % V/V for hydrogen, compared with the normal atmospheric oxygen content of 21 % V/V. It is usual in practice to include a factor of safety; a maximum oxygen content of 8 % V/V is frequently specified for hydrocarbons.

6.1.2 Explosives

These are mixtures or compounds whose violent exothermic reaction can be initiated by electrostatic discharges or other sources of ignition without the intervention of air.

6.2 Ignition energy

Whether or not an electrostatic discharge will ignite a flammable mixture depends upon the composition and temperature of the mixture, the energy of the discharge and the distribution of this energy in space and time. In practice the most frequent source of ignition is a spark from an insulated conductor, and a spark is therefore the commonly accepted means of measuring ignition energies, using a voltage of at least 10 kV. For a given flammable material a graph of the lowest energy for ignition as a function of concentration in air takes the form shown in Figure 2. The energy corresponding to the lowest point on this curve is called the minimum ignition energy and is the best general measure of the smallest quantity of energy needed to initiate an explosion or fire involving the flammable material in question.

A detailed review of ignition energy data for gases has been compiled by Lewis and Von Elbe of the US Bureau of Mines²⁾. Most organic vapours and hydrocarbon gases in air have minimum ignition energies in the range 0.01 mJ to 1 mJ. Carbon disulphide and hydrogen in air have values in the region of 0.02 mJ, while explosives can have minimum ignition energies as low as 0.001 mJ.

²⁾ *Combustion flames and explosions of gases*, Lewis and von Elbe, Academic Press Inc., 1961.

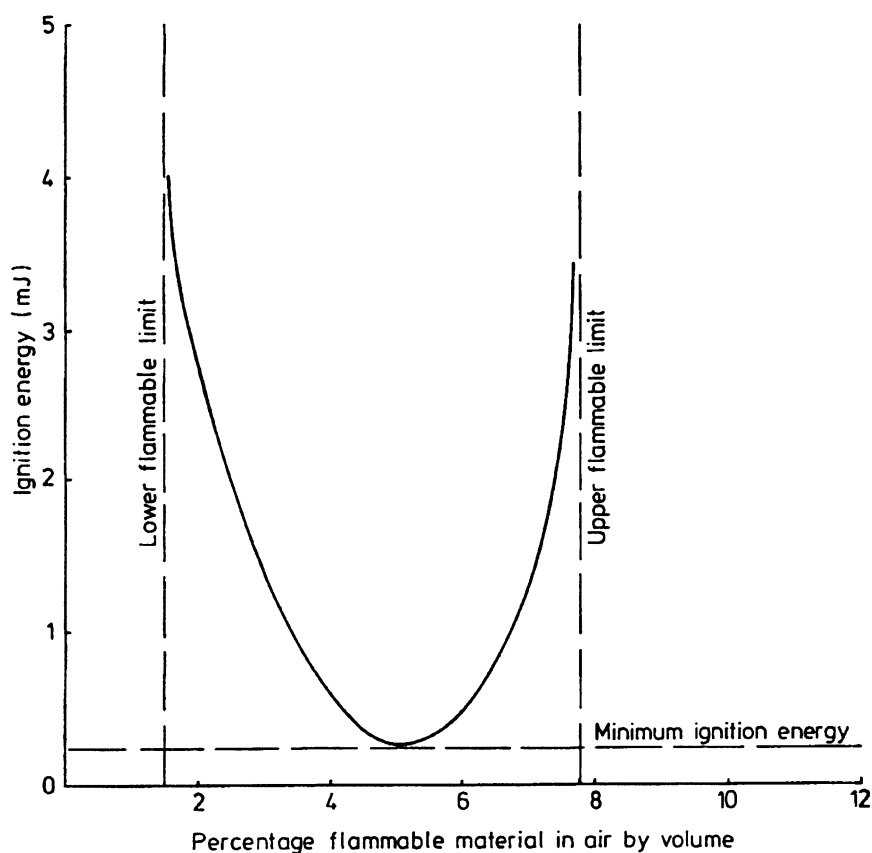
Similar considerations apply to dust clouds or liquid droplet suspensions except that the minimum ignition energies are higher than those of gases because of the need to heat up the suspended matter present. For dust clouds the values range from less than 2 mJ to greater than 5 000 mJ.

The minimum ignition energy of a dust cloud depends on the particle size distribution in the cloud, as well as on its chemical composition, although published data frequently do not specify the particle size. A decrease in particle size or an increase in the percentage of fines in general decreases the minimum ignition energy. In some cases this effect is very marked, as in the example given in Table 2.

As a practical guide, experience suggests that the sensitivity of a dust cloud to ignition is realistically determined by using dust that has passed through a 200 mesh (75 µm) sieve. For a mixture of flammable gases and dusts take the minimum ignition energy of the mixture to be that of the most sensitive component.

6.3 Assessment of the incendivity of discharges

Sparks from insulated conductors constitute the most important electrostatic ignition risk. As discussed in 5.2, sparks are of very short duration and, in many cases, virtually all the available electrostatic energy appears in the discharge. To assess the incendivity of such a discharge, therefore, it is usually valid to compare the stored energy, measured by $\frac{1}{2} CV^2$, with the minimum ignition energy of the combustible material in question. The comparison may not be valid if there is resistance in the discharge path, because part of the stored energy may be dissipated in the resistance and the duration of the spark may increase.



NOTE. This graph is purely diagrammatic and is not to be used in any assessment of incendivity.

Figure 2 — Ignition energy as a function of flammable material concentration in air

Table 2 — Example of dependence of minimum ignition energy on particle size of a dust

Particle size range	Minimum ignition energy
μm	mJ
710 to 1 680	> 5 000
355 to 709	250 to 500
180 to 354	50 to 250
105 to 179	< 10
53 to 104	< 10
5	< 10

The incendivities of corona discharges are less than those of sparks. The stored energy on a conductor, $\frac{1}{2} CV^2$, therefore tends to overestimate the ignition risk. The relatively low incendivity of corona allows it to be used in passive eliminators as a means of safely removing static electricity, although, if there is any possibility of the presence of a flammable mixture, it is essential that great care be taken in the design of the system.

There is no generally accepted method of determining the incendivity of brush discharges from non-conductors. Brush discharges have limited energy but can ignite most gases and vapours and some sensitive dusts. Brush discharges can be more incendive than corona. A propagating brush discharge from a high resistivity non-conducting sheet, with or without a metal backing, is highly incendive. Where a precise assessment of the incendivity of a brush discharge is required, ignition tests should be made using the flammable mixture of interest. In the case of a propagating brush discharge, if the total energy stored on the non-conductor can be estimated, it may be compared with the minimum ignition energy of the flammable atmosphere.

7 Physiological effects of electrostatic discharges

The smallest spark energy that a person can feel when a discharge occurs to or from his body is about 1 mJ, that is, a potential of about 2.5 kV if his capacitance is 300 pF. As the potential is increased, variations in response are observed. Some people find 10 mJ uncomfortable due to muscular contraction, whereas others can accept several hundred millijoules before they experience sharp muscular contraction. 1 000 mJ, i.e. 1 J, affects everybody severely. In incidents in which people have been rendered unconscious the energy of the discharge was estimated to be several joules.

Since in most situations discharge energies are below 100 mJ, serious physiological shock is very rare. There are exceptions, e.g. a discharge to a person due to highly charged particulate matter collected in a non-conducting container can be as much as several joules (see 10.2.3). Irrespective of whether the shock itself is harmful, the involuntary muscular reaction to a discharge may cause an accident through, e.g. the dropping of a tool or by precipitating a fall.

Section 3. Electrostatic hazards and their control

8 Electrostatics in liquids

8.1 Charge generating mechanisms

8.1.1 Flow of single phase liquids through pipes

When a liquid flows through a pipe, charge separation occurs (see 3.2) and the liquid emerging from the pipe is charged. The amount of charge is dependent, amongst other things, upon the flow conditions. Turbulent flow generates more charge than laminar flow; for a single phase liquid the current generated is roughly proportional to the velocity in the case of laminar flow and to the square of the velocity in the case of turbulent flow. Because laminar flow problems are less severe, this Part of BS 5958 deals exclusively with turbulent flow conditions.

For single phase flow, the current generated by a liquid flowing through an infinitely long pipe, made of metal or of any material with a volume resistivity less than about $10^{12} \Omega \text{ m}$, does not change greatly with the conductivity and relative permittivity of the liquid. In practice, as the liquid leaves the pipe it is no longer subject to the charge separation process and charge relaxes back to the wall of the pipe through the emerging liquid. Therefore the net current carried by the liquid as it enters the receiving vessel decreases as the liquid conductivity increases. Also, as the flow rate decreases, the current decreases.

For single phase liquids whose conductivities are low enough for them to retain a dangerous charge, there are a number of empirical relationships giving maximum charging currents for infinitely long pipes. One of the widely used relationships is the Schön equation:

$$i_s = Kv^2 d^2$$

where

i_s is the maximum streaming current (in μA);

v is the velocity of the liquid (in m/s);

d is the diameter of the pipe (in m);

K is a constant of $4 \mu\text{A s}^2/\text{m}^4$.

This relationship approximately represents the current (in microamperes) generated in industrial scale pipes.

Liquid charging can also be expressed in terms of charge density. The Schön equation leads to the following approximate expression:

$$\eta \approx 5 v$$

where

η is the charge density (in $\mu\text{C}/\text{m}^3$);

v is the linear velocity of the liquid (in m/s).

Thus, for linear velocities of 1 m/s and 10 m/s the charge densities are about $5 \mu\text{C}/\text{m}^3$ and $50 \mu\text{C}/\text{m}^3$ respectively.

For practical purposes the pipe can be considered to be of infinite length if

$$L > 3v\tau$$

and

$$\tau = \frac{\epsilon\epsilon_0}{\gamma} \times 10^{12}$$

where

L is the length of the pipe (in m);

τ is the relaxation time of the liquid (in s);

ϵ is the relative permittivity of the liquid;

ϵ_0 is the permittivity of free space
($8.85 \times 10^{-12} \text{ F/m}$);

γ is the conductivity of the liquid (in pS/m).

Very little data is available for charge generation during liquid flow in pipes made of materials having volume resistivities greater than $10^{12} \Omega \text{ m}$. It has been found that for liquids with conductivities in the range 1 pS/m to 100 pS/m the current leaving a polyethylene pipe decreases with increasing duration of the flow and finally reaches an equilibrium value in good agreement with that from a metal pipe. On this evidence, the expression for charge generation by a conducting pipe can be used to estimate the equilibrium generation by a non-conducting pipe. However, prior to the establishment of equilibrium, the current is greater than that for a conducting pipe, but this is unlikely to affect the degree of hazard in a sustained pumping operation.

8.1.2 Flow of liquid/liquid or liquid/solid mixtures through pipes

Whenever such mixtures are pumped through pipes, charge generation occurs in the same way as with a single phase liquid. The rate of generation may be greater than with a single phase because of the increased interfacial area, but it is not amenable to calculation.

8.1.3 Flow of liquids through strainers and filters

Strainers and gauzes are very coarse filters, usually with mesh numbers less than 350 (30 μm apertures), designed to remove large particles from liquids. They do not normally cause any significant current generation and can be ignored when handling single phase liquids. If a second phase is present they may aid its dispersion, thereby promoting increased charge generation elsewhere in the system.

Fine particle filters can be prolific generators of static electricity; in general, the more stringent the filtration requirement, the greater the charge generation. The current generated by very fine micronic filters can exceed, by several orders of magnitude, that produced by a pipeline. Typical charge densities in the liquid leaving such a filter can be in the range 10 $\mu\text{C}/\text{m}^3$ to 5 000 $\mu\text{C}/\text{m}^3$.

Unfortunately it is not possible to predict the charge generation of a fine particle filter; even apparently identical filters of the same type can give widely differing results.

Current generation in a fine particle filter depends upon flow rate, liquid conductivity, the type of ions in the liquid and, possibly, the state of the filter element surfaces. In general, generation increases with increasing flow rate. As the liquid conductivity increases from a very low level (0.1 pS/m), generation at first also increases. This is because the increasing ion concentration makes a positive contribution to both conductivity and charge generation.

However, the current emerging from the filter reaches a maximum and then declines with further increase in conductivity as the normal relaxation process carries charge back to the filter. The lack of predictability of the current generation is attributed to variations in the nature and concentration of the ions present and to the complexities of the liquid/filter element interface.

8.1.4 Settling of solids or liquids in liquids

Any settling process, such as that of water in hydrocarbon, generates charge. The process of charge generation in such systems is very complicated and has been studied only to a very limited extent. Low conductivity of the continuous liquid phase promotes the occurrence of a high settling potential by retarding relaxation.

8.1.5 Splashing of liquid jets

As liquid emerges from a pipe into a receiving vessel two processes may give rise to charged mist or spray.

In the first, the liquid is charged during its flow through the pipe as described in 8.1.1 and, if the liquid column is unbroken, part of the charge relaxes back to the pipe. If, however, the column breaks up into droplets, any remaining charge is distributed amongst the droplets. The resultant spray is therefore charged.

Secondly, if the jet hits an obstruction, additional charge can be produced by contact electrification at the point of impact and the resultant spray may therefore be highly charged. The magnitude of this charge is not predictable; it depends upon the nature and cleanness of the surface as well as on the type and concentration of ions in the liquid. In general, the more conducting the liquid, the greater the charge generation. For example, a water jet produces more charge than an oil jet, but water/oil mixtures may produce more than either water or oil.

8.1.6 Ejection of liquid droplets from a nozzle

A wet gas stream issuing from a nozzle can be highly charged. The liquid layer on the inside of the pipe is sheared by the gas stream and broken up into droplets. If the sheared layer has a charge as a result of its motion along the pipe surface, the droplets emerging from the nozzle are charged. The amount of charge depends, amongst other things, on the conductivity of the liquid and on the gas velocity.

8.1.7 Stirring and mixing

Any motion of a liquid in a container generates static electricity, to an extent dependent upon the conductivity of the liquid and the relative motion between the liquid and the solid surfaces with which it is in contact. Normally, the amount of charge generated is much less than that produced by the flow of a liquid through a pipe or a fine filter, because the turbulence is less, but a hazard can arise in some blending operations.

8.2 Discharges involving liquids

8.2.1 General

For some processes it is possible to calculate both charge generation and charge retention (see 5.2) and hence to assess the degree of hazard due to a discharge and to decide upon countermeasures. In many other cases, however, calculations are impossible and measurements have to be relied upon. This usually involves the use of electrostatic voltmeters or electrostatic field meters to monitor the problem and to determine the critical parameters. Because charge generation is very variable it is important to be satisfied that the worst case has been tested.

8.2.2 Discharges from liquids

Charges that have been separated as a result of the flow of a liquid attempt to recombine. If the liquid has a low conductivity it can, however, retain the charge, irrespective of whether it is pumped into an earthed, conducting (normally metal) tank or into a non-conducting tank or container.

A measure of the rate of charge dissipation from a liquid in contact with earthed metal is its relaxation time, τ (in seconds), the expression for which was given in 8.1.1. It is the time required for the potential of the liquid to fall to about 37 % of its original level as it decays exponentially. It is accepted in many applications that if a liquid has a conductivity greater than 50 pS/m, equivalent to a relaxation time of about 0.35 s, it is incapable of retaining a hazardous charge. Alcohols and ketones are normally in this category. In certain situations (e.g. agitation) a conductivity of 1 000 pS/m may be required to prevent the retention of hazardous levels of charge. These situations are given in BS 5958-2 (e.g. clause 10). Clean and white oils such as kerosene or gasoline, however, normally have conductivities below 50 pS/m and are therefore able to retain a significant charge.

When a liquid is charged, electric fields exist both within the liquid and in the space around it. If these fields are high enough, discharges can occur.

Discharges within the liquid are, in general, not an ignition hazard, but they may bring about chemical changes altering the specified properties of the liquid or causing corrosion of the plant involved.

Discharges in the atmosphere can be hazardous. Within a tank, the field strength between the liquid surface and earthed walls or structure can exceed the breakdown strength. It is rarely possible to estimate the energy of the resultant discharges and, in any event, this energy cannot be compared with the minimum ignition energy determined using metal electrodes.

It is sometimes possible to avoid a hazardous situation by controlling the rate of charge input to the tank so as to keep the field strength at the liquid surface below the breakdown value. This field strength can, in principle, be calculated from the input current given information on the conductivity of the liquid, the size and shape of the tank and of any internal structure, and the ullage of the liquid.

Charge retention on liquids is similar in both conducting and non-conducting containers although in the latter case relaxation may be controlled by the resistivity of the container. A non-conducting container can be expected to increase the possibility of discharges from a liquid, but little quantitative data is available on this subject.

8.2.3 Discharges from solids

Both non-conductors and conductors with a resistance path to earth greater than $10^6 \Omega$ can become charged through the agency of a liquid by many processes. These include:

- a) flow of a liquid past them (the charge may be due to contact electrification between the liquid and the object, or to charge transfer from a liquid already carrying charge; examples are an insulated metal flange, an insulated section of metal pipe in a non-conducting pipeline or a length of non-conducting pipeline itself). The level of liquid conductivity in which a hazardous situation could result is given in the relevant clauses of BS 5958-2;
- b) collection of charged liquid, as when charged liquid is poured into an unearthed can;
- c) immersion of a conducting object in charged liquid (the object takes up the potential of the point where it is situated in the liquid; an example is an unearthed metal component in a sampling or ullaging system);
- d) settling of charged mist or spray on the object, e.g. an unearthed object in the vicinity of a steam leak.

The possibility of charging by induction should always be borne in mind where there are insulated conductors in the vicinity of charged liquid.

As described in clause 5, the discharges from conductors are usually sparks and are potentially hazardous. The energy can be calculated using the procedure given in 5.2. In some cases, e.g. an empty can floating in a liquid, the conductor may be mobile, and the calculation is then complicated because the capacitance is variable.

Discharges from non-conductors are considered in clause 10.

8.2.4 Charge retention on mists and sprays

Suspensions of charged droplets retain their charge by virtue of the insulation provided by the surrounding atmosphere. When the mist or spray is being produced continuously, as, for example, when washing a tank with water or injecting steam, the charge density builds up to an equilibrium value where the rate of input of charge is equal to the rate of loss by processes such as settling or impingement of the droplets on the structure of the tank.